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by

F.D. Barlow, F.E. Robitaille, and J.H. Renick

Atmospheric Sciences Department
Alberta Research Council
Edmonton, Alberta

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F.D. Barlow, F.E. Robitaille, J.H. Renick

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ABSTRACT

A principal component of the water resource in southern Alberta is runoff from the accumulated winter snowpack on the slopes of the Rocky Mountains. This water resource is essential for the significant irrigation agriculture of this region. Variations in this mountain snowpack have important effects on the current and future agricultural development of southern Alberta.

The application of cloud seeding technology to maintain or augment the mountain snowpack is being examined and tested in the western United States. This seeding of winter orographic clouds to produce additional snow, and thus increase the snowpack runoff, is being examined in the U.S. as a cost effective method of meeting water needs. The Alberta Research Council has initiated a preliminary project to examine the feasibility of applying these cloud seeding techniques to southern Alberta to supplement the snowpack water resource.

This paper provides an overview and summarizes some results of recent studies on snow in Alberta by the Research Council. This effort is focused on providing background information on snow climatology and winter cloud characteristics for the southern Canadian Rockies. An instrumented research aircraft has been used to document the characteristics of winter clouds and to assess the precipitation efficiency of the cloud systems. Preliminary results indicate that a potential exists for augmenting the snowfall over the Rockies of southern Alberta. The possible application of such technology to the Alberta situation will be discussed.

1 INTRODUCTION

The principal water source for the agricultural, domestic and industrial requirements of southern Alberta is the accumulated winter snowpack on the eastern slopes of the Rocky Mountains. This water resource provides the means for the significant irrigation agriculture of this region. Its continued supply is essential to the future economic development and environmental quality of the South Saskatchewan River Basin.

Future demands for water in the South Saskatchewan Basin may not be satisfactorily fulfilled. This is due to both the natural variability of the water supply and high rates of water usage, primarily for irrigation. The potential shortage of water is particularly acute for the Oldman River basin which currently has over 600,000 irrigated acres, with a potential for over 1,300,000 irrigated acres (ECA, 1982). This paper presents the possibility of increasing this water supply by augmenting the mountain snowpack at higher elevations.

The Alberta Research Council (ARC) has initiated a preliminary project to examine the feasibility of supplementing this snowpack through the controlled use of cloud-seeding techniques. This projects's initial aim is to measure and analyze the precipitation processes of the snow-producing orographic clouds. The project study area straddles the Alberta-British Columbia border (Figure 1), and includes the Oldman River basin. This paper provides a brief overview of cloud seeding for snowpack augmentation and summarizes some of the results of the ARC's snow research effort.

2 CLOUD SEEDING FOR SNOWPACK AUGMENTATION

The rationale of cloud seeding for snow augmentation is based upon the fact that the atmosphere may not be naturally "efficient" in producing precipitation. Considerable quantities of moisture are contained in the atmosphere as it passes over the mountains. For example, in a moderate westerly air flow with clouds one-half mile deep and extending sixty miles along the mountains, about one million gallons of water pass over the mountains and evaporate each minute. Some of this moisture condenses to form clouds which often do not produce precipitation. There are atmospheric conditions when cloud seeding can be used to make these clouds snow in the mountains.

Air flowing over mountain barriers often create clouds composed of water droplets, depending on the air's temperature, moisture conditions and vertical motion. Under natural conditions these cloud droplets remain in the liquid state at temperatures colder than zero degrees (0 °C) due to a scarcity of ice-forming nuclei in the free atmosphere. Any ice particles that are present in these supercooled clouds grow at the expense of the droplets and may eventually become larger particles that reach the surface as snow. In the absence of ice, these cloud droplets evaporate in the descending air on the

leeward side of the mountain barrier.

Cloud seeding involves the delivery of "artificial" ice nuclei, either from silver iodide smoke or injected dry-ice pellets, to the regions of supercooled liquid water within clouds. These artificial ice nuclei then greatly increase the concentration of the ice crystals which use the available cloud water to grow into precipitation-sized particles. Sufficiently large particles may grow into snow crystals that eventually fall as snow to the surface. Thus, more of the cloud water would be converted to snow and not lost to evaporation on the barrier leeward side. The increased snowpack would then provide additional streamflow during spring melt.

Cloud seeding for snowpack augmentation has been undergoing research and development in the western United States to help alleviate potential water shortages. Projects are being conducted by various universities and state and federal agencies including the U.S. Department of the Interior and the National Oceanic and Atmospheric Administration (NOAA). These projects are currently being conducted in various western states including California, Colorado, Montana, Nevada and Utah.

Cloud seeding in the mountains has been recently identified by a United States Secretary of the Interior as "the most cost effective and promising means of meeting the water needs of the Colorado River basin." (CREST, 1983). Recent results from the U.S. indicate that cloud seeding may be able to increase the mountain snowpack by about 15% (Super and Heimbach, 1983; Cleveland, 1978). In Colorado, it has been estimated that such increases could yield increased streamflows by 10%, or an additional 2.3 million acre-feet for the Colorado River basin (CREST,1983).

3 SEEDING POTENTIAL OF ALBERTA WINTER CLOUDS

The Alberta Research Council has conducted some preliminary research into the feasibility of applying snow augmentation techniques to the southern Canadian Rockies. This limited initial effort has focused on providing background information on the snow climate and winter cloud characteristics within the area. The purpose of the climatological study is to provide general information on the snow regime within the project area (Barlow, et al., 1983). In addition, an instrumented research aircraft is being used to document the characteristics of winter clouds and to assess the efficiency of the winter cloud systems to determine if a potential "seeding window" exists (Renick et al., 1979). This summary will note some of the key findings of these aircraft measurements.

The principle component of the ARC snow research effort is the in-situ measurement of cloud characteristics. To this end, the Intera/ARC Cloud Physics research aircraft was used in March 1982 and three subsequent periods to measure the properties of clouds over the southern Rockies. This research has concentrated only on documenting

the characteristics of natural clouds and no cloud seeding has been conducted.

Four two-week field measurement periods have been completed. Research flights were made on a total of 29 days with a combined flight time of 108 hours. Significant cloud cover has been unfortunately rare during these field periods, but measurements within orographic cloud systems have been made on seven (7) flight days. The results of a generalized climatological analysis and a significant case study and are presented here.

3.1 Cloud Liquid Water Climatologies

A goal of the aircraft research program is to document the general occurrence and distribution of liquid water and ice crystals within winter clouds over the study area. The purpose is to determine the general "seedability" of the clouds based upon their microphysical characteristics.

The preliminary results of the analysis of aircraft data collected on Feb. 09, 1984 are noted here. A total of 17 penetrations of cloud were made during flights on this day. These measurements were made near the upper edge of a stratocumulus deck that extended across the divide and became mostly broken to the east. Cloud bases were approximately ten thousand feet with tops just above twelve thousand feet.

The absolute amount of liquid cloud water is a major consideration for seeding assessment. The presence of sufficient liquid water, with the concurrent absence of natural ice crystals, indicate that a potential for seeding exists. The distribution of the relative frequency of the one-second measurements of in-cloud liquid water is given in Figure 2. Over 55% of the values exceed the 0.10 g per cubic metre minimum for a seeding potential cited for the Sierra Mountains (Marwitz and Stewart, 1981). Ice crystal concentrations for these were all less than 10 per litre, commonly around 1 per litre. This combination of available liquid water and low ice would suggest that many of these clouds would meet the criteria for being "seedable" (Heggli et al., 1983).

Cloud liquid water values were also measured during flights on 15 and 27 March, 9 and 10 December, 1983 and February 1 and 8, 1984. The average liquid water values were generally 0.1 to 0.2 g per cubic metre with peak values approaching 0.9. Analysis of these flights is continuing.

3.2 March 23, 1982 Orographic Cloud Case Study

The ability of winter clouds to efficiently convert available liquid water to precipitation is a central element in determining the

potential for cloud seeding. If winter clouds over the Rockies are naturally efficient, then cloud seeding would not be effective. A detailed case study of the efficiency of a cloud system would assist in determining seeding potential.

A notable case study was the 23 March, 1982 flight within an orographic snow-producing cloud containing regions of supercooled liquid water as high as 0.6 grams per cubic metre. The results of this case study are summarized briefly here. This analysis was performed principally by Terry Krauss (Krauss et. al., 1983).

This study examined the processes of a large cloud complex that formed over the project area as a result of orographic lifting and saturated upslope conditions. Six cloud passes were made through this quasi-stationary system. A vertical cross-section of the cloud liquid water measured in this case study is illustrated in Figure 3.

The precipitation efficiency of the cloud can be examined using the precipitation particles measured by the aircraft 2D-P optical probe. Assuming the particles are thick plates, the total mass of the precipitation can be roughly estimated. Using parcel theory and the upwind environmental sounding, a rough estimate of the precipitation efficiency is indicated schematically in Figure 4. These values should be interpreted as relative, but do indicate substantial differences. The regions of liquid water greater that 0.2 g per cubic metre are frequently less than 50% efficient in precipitation conversion. The "excessive" efficiencies on the eastern edge may reflect the high upslope liquid water values and enhanced ice crystal growth environment.

These results suggest that, over the mountains, the liquid water was not efficiently converted to precipitation and that the precipitation process could be made more efficient if artificial ice nuclei were added.

4 SNOW AUGMENTATION AND ALBERTA

The preliminary results of these cloud measurements indicate that a potential exists for increasing the snowfall from clouds over Alberta's Rocky Mountains. The encouraging results from nearby U.S. projects suggest that snowpack increases on the order of 10 to 15% may be possible. The headwaters of the Oldman River would be an appropriate region for the application of this technology. Assuming a 10 to 15% increase in snowpack, such application may yield an additional 250,000 acre-feet of water annually within this basin. Efficient use of the extra water produced from this augmented snowpack would require adequate storage and distribution.

The application of snowpack augmentation would require a detailed research plan designed for the Alberta situation. Essential elements of any research program would include benefit/cost analyses and studies on environmental and social impacts, possible extra-area

effects, and rigorous scientific evaluation. Acquisition and adaptation of this technology to Alberta would require about three winters. After this, a period of testing and evaluation would be needed prior to any operational use.

Costs for water produced by snow augmentation from cloud seeding have been estimated to be about five to seven dollars per acre foot in the United States (CREST, 1983). For the Colorado River basin case, the benefit-to-cost ratio has been estimated as ranging between 9 and 12 to one. No estimates for the Alberta case have as yet been made.

Minimal social or economic disruption from increased snow is expected. Cloud seeding would be applied to increase the snowfall at higher mountain elevations, above areas used for habitation and livestock grazing. Highways would not experience significant increases in snowfall because of they are lower in elevation and some distance from possible accumulation areas.

In addition, cloud seeding is a flexible approach for water management. A decision to employ or to suspend cloud seeding could be made on a year-to-year basis or even on a storm-to-storm basis. Seeding is most effective when precipitation rates are light to moderate. Consequently, heavy snowfalls would not be treated and seeding would be suspended during high snowfall years.

5 CONCLUSION

The recently initiated snow research effort at ARC has provided a preliminary look at the potential for snow augmentation in the southern Canadian Rocky Mountains. Current research efforts are focusing on the analysis of the data collected during the previous field seasons. A continuing climatological study will attempt to delineate the snow climate and assist in the design of any possible seeding projects. The aircraft measurements, the first of their kind in Canada, indicate sufficient liquid water occurs in winter clouds over the Mountains for cloud seeding. Continued analysis of the aircraft data will help to determine the extent and magnitude of this seeding potential.

In conclusion, adapting this technology to Alberta may provide a flexible and cost effective means of complementing the development of southern Alberta's water resource.

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FIGURE CAPTIONS

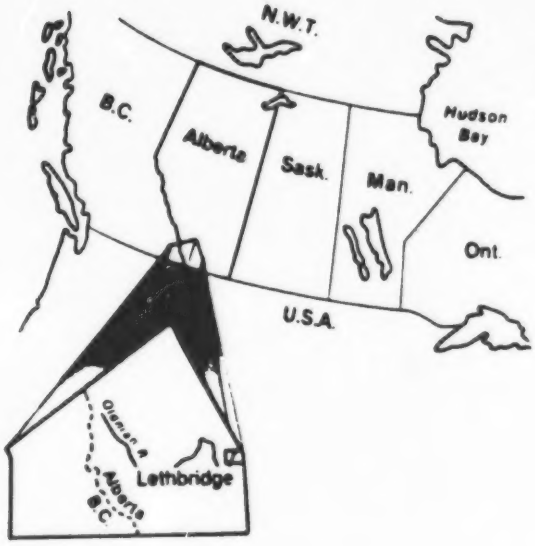
Figure 1. Alberta Research Council Snowpack Project Area.

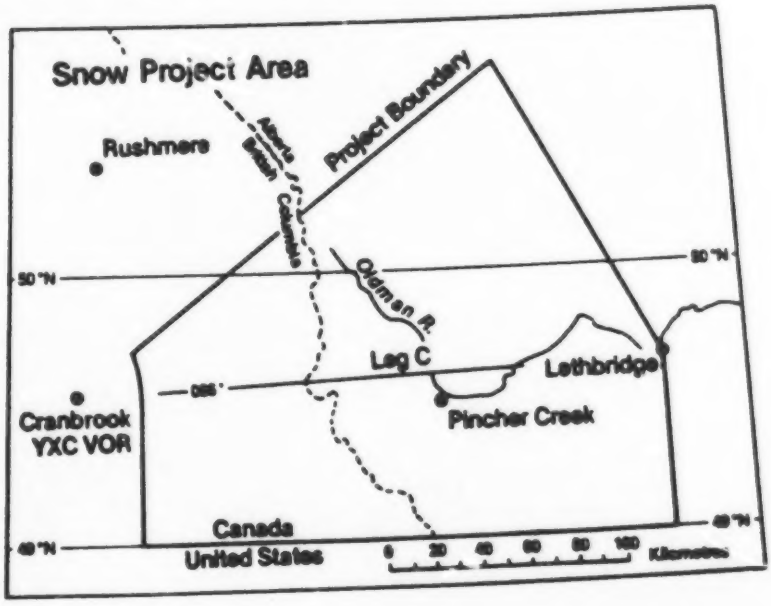
Figure 2. Frequency distribution of in-cloud liquid water content for cloud penetrations made on February 9, 1984.

Figure 3. Liquid water measurements made within cloud of 23 March, 1982 case study. (from Krauss et. al., 1983, p. 93)

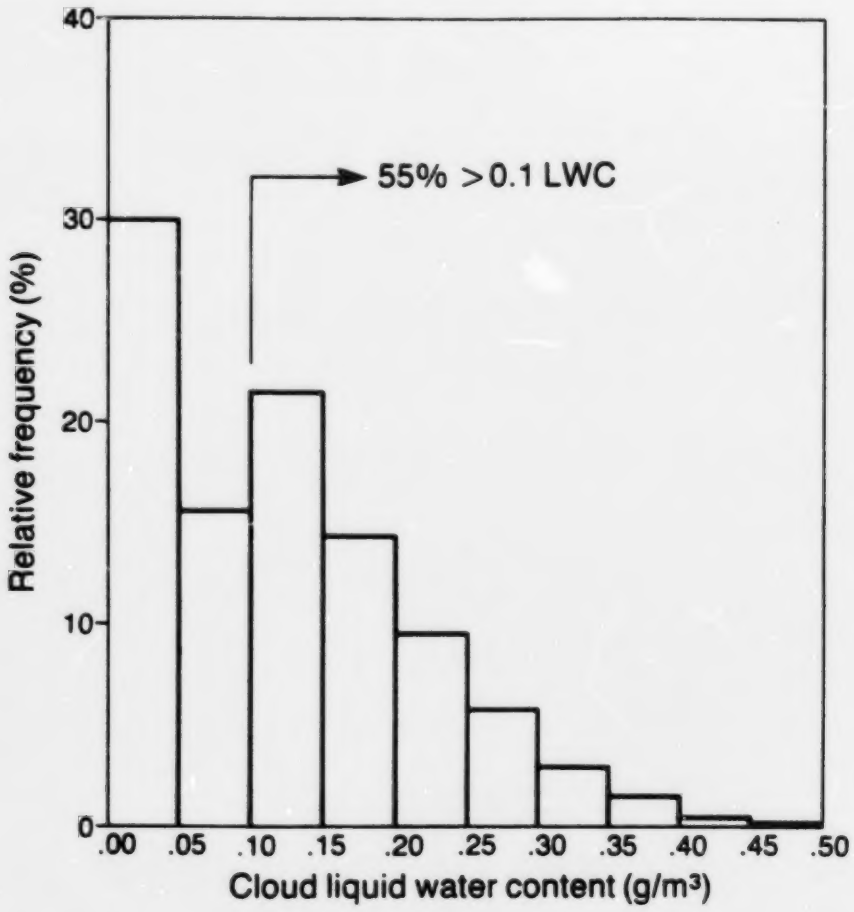
Figure 4. Calculated precipitation conversion efficiency within cloud of 23 March, 1982 case study. (from Krauss et. al., 1983, p. 98)

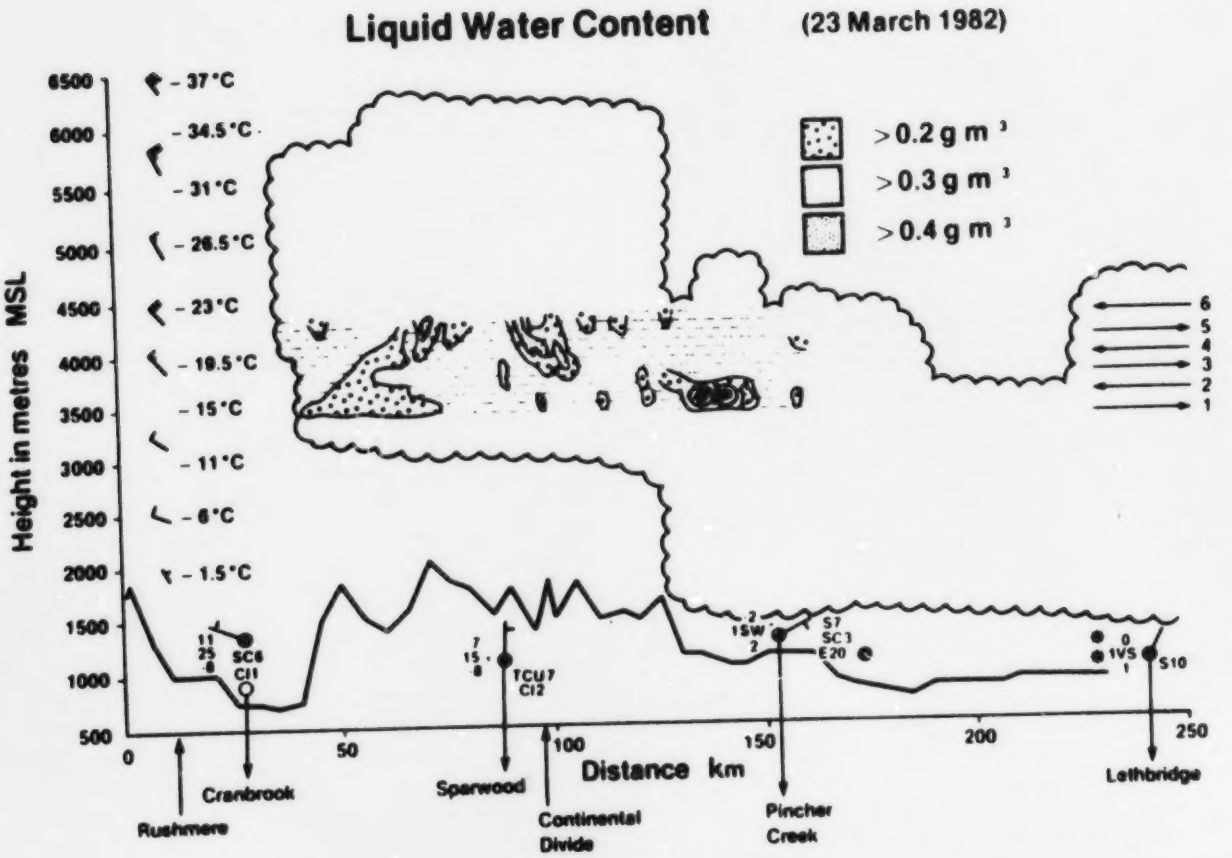
Location of Snow Project Area





Cloud Liquid Water Content - February 9, 1984

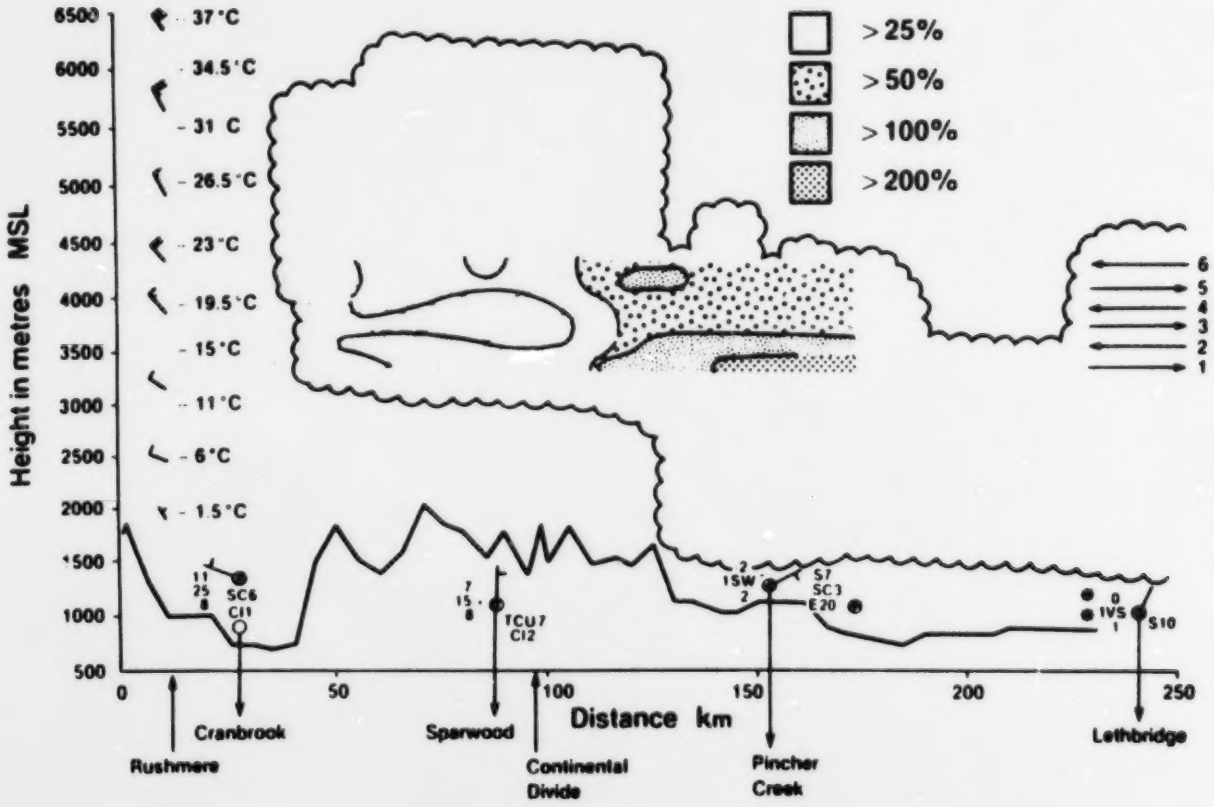




A schematic vertical cross section along Leg C of the cloud system and the measured liquid water contents on 23 March 1982. The liquid water contents represent 10 s averages (approximately 1 km distance) from the Johnson- Williams hot-wire probe. The vertical profile of wind (full barb equals 10 m/s) and temperature from the mobile rawinsonde at Rushmere is located along the vertical axis. The terrain height and surface weather observations at Cranbrook, Sparwood, Pincher Creek, and Lethbridge are shown along the horizontal axis. The locations and directions of the six research aircraft cloud penetrations are indicated.

(from Krauss, et.al., 1983)

Precipitation Conversion Efficiency (23 March 1982)



The precipitation conversion efficiency of the cloud system on 23 March 1982. The precipitation conversion efficiency is defined as the ratio of Ice Water Content to Total Vapour Condensed as determined from the environmental sounding at Rushmere.

(from Krauss, et.al., 1983)